Space Weather Technical Forecast

Issued on Friday, 10 May 2024 at 13:30 Local

This technical forecast provides a four-day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: G2-G3 (Moderate to Strong) Expected late 10 May into 11 May, Chance of G4 (Severe) intervals. Further R3s (Strong flares) Likely.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Solar activity has remained High in the past 24 hours, with X-ray activity recorded at GOES16 showing frequent M-class activity, peaking with an X3.9 from AR3664 at 10/0706UTC. This was preceded by an X1.1 09/1743UTC from the same active region. There are currently seven sunspot groups on the disc, with large and complex Ex-AR3663 now no longer visible on the northwestern solar horizon as another significantly smaller and simpler unnumbered region is arriving over the eastern solar horizon.

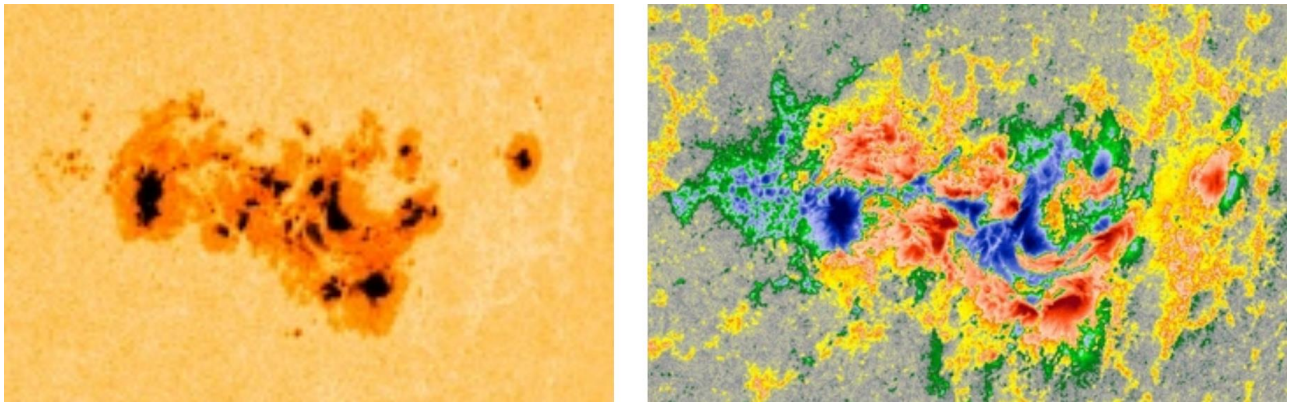

Figure 0a: 10/1200UTC HMIIF and HMIBC showing high degree of complexity in AR3664 – the expected source of much of the coming four days' space weather activity.

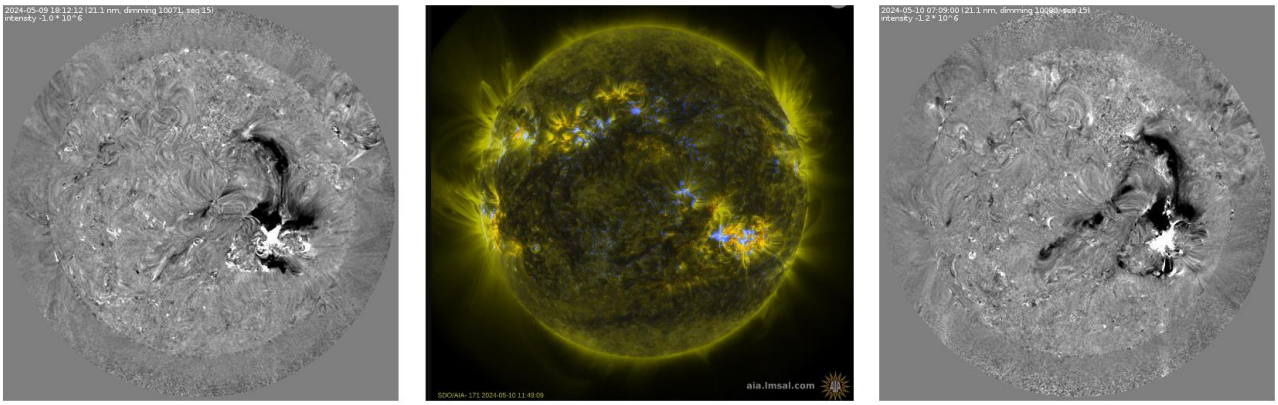

Figure 0b: SIDC ROB dimmings of X1.1 flare from AR3664 (left); X3.9 flare (right) and AIA171 and HMIBC for the whole disc for 10/1200UTC. Both dimmings have EIT waves, Type II and IV radio bursts asscoiated with them.

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AR3664 is by far the largest and most complex region on the disc, as has been the case for recent days. It currently presents as a Zurich Fkc with Mt Wilson Beta-Gamma-Delta classification. While recent imagery perhaps suggests a very slight reduction in overall penumbral area to 2400mhs, its longitudinal span has topped 24 degrees and there are several Mt Wilson deltas nestled within. Imagery suggests there has been some consolidation of late of the intermediate spots, however there is shear and major distortion in the leaders in particular, and its most recent effort of an X3.9 at 11/0706UTC proves that it remains a very potent spot group. Activity in other active regions paled in comparison, however perhaps the most significant trend in the remainder of the front side groups was continued emergence of AR3672 in the northeast, which is now a Csi/Beta-Gamma.

The two X-class flares of the past 24 hours both have Coronal Mass Ejections (CMEs), Type II and IV radio bursts associated with them. The earlier and smaller (in terms of X-ray flux) of the two has been modelled in MOSWOC Enlil and crosses 1AU around the turn of the UTC day 11 into 12 May as a standalone feature (i.e. not an agglomeration of several CME fronts). This is directed largely ahead of the track of the Earth's orbit, but with a reasonably strong glance modelled. This feature was modelled with a speed of 888km/s versus the Type II estimated speed of 303km/s. The precise arrival time is under review.

The second CME is now emerging from the occulting discs of Lasco C2,C3 and STEREO COR2 imagery. This appears to share the character of much of the recent activity from AR3664, and will be analysed once further imagery becomes available. This event was accompanied by Type IV and II radio bursts, with the latter having an estimated speed of 1248km/s, and it may therefore catch up with its predecessors to amplify any activity - this aspect is TBC.

The only other noted possible CME event of the period was one from behind the northeastern limb seen around 09/1800UTC in e.g. AIA211 imagery. This is visible on coronagraph imagery but plays no part in the forecast.

Solar Wind / Geomagnetic Activity: Solar winds, as observed by DSCOVR and ACE at L1, were relatively steady at Slightly Elevated levels throughout, averaging around 425km/s. The solar wind density showed a very slight rising trend, mainly confined to typical single figured ppcc, but with an eventual rise to nearer 10ppcc by the period's end. The IMF was relatively erratic in magnitude but remained within Background levels, peaking at 7nT mid-period. The north-south component was variable with a range between +4 and -6nT. The phi angle showed a gradual drift from being mainly positively-aligned (away) to mainly negative into the current UTC day.

The net result of the above solar wind measures was Quiet throughout, provisionally with five successive peaks of Kp2+ starting from the UTC overnight period.

Energetic Particles / Solar Radiation: High energy proton flux (greater than 10MeV) observed at GOES18 showed a slow and steady upward trend in the wake of recent strong flares, rising from around 0.5pfu to 4pfu over the period as a whole (i.e. significantly below S1 at 10pfu). Higher energies were unmoved.

High energy electron flux (greater than 2MeV) observed at GOES16 was at Normal Background to Moderate levels, with peaks near 200pfu at 09/1740UTC. The associated 24-hour fluence was well below the Active threshold. Observed fluence at 10/0001 UTC was 4.62e6 integrated pfu, with a roughly level tendency.

Four-Day Space Weather Forecast Summary

Solar Activity: Further X-class flares are Likely, while M-class are Expected on all days of the period. The sunspot responsible - AR3664 - is present throughout, and there are signs of large eastern solar horizon arrivals to at least in some way mitigate for the recent loss of Ex-AR3663

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over the northwestern limb.

Solar Wind / Geomagnetic Activity: The geomagnetic forecast is CME-dominated, with the main uncertainties being 'when' rather than 'if' CMEs arrive. Multiple Earth-directed CMEs were observed leaving the Sun between 08 and 09 May associated with solar flares from AR3664 in the southwest. Added to this is a large filament liftoff from the northeast disc on 08 May. Due to the relative speed of the various CMEs most are expected to combine into a single larger arrival towards the end of the UTC day on Day 1 (Friday 10 May). The X1.1 mentioned in the solar activity section is perhaps the main exception to this, and should arrive later at around 12/0001UTC. The latest and largest flare of the current 24-hour period (X3.9) is undergoing assessment, but could sweep up the X1.1 outlier in a manner similar to events forecast on 10 May - this aspect is to be confirmed.

Other drivers of geomagnetism are expected to be masked and pale in comparison to the CME effects, however should any sizable windows emerge that escape CME influence (considered unlikely), Slightly Elevated solar winds are expected to fall to Background levels on Day 1 (10 May). A minor coronal hole enhancement is possible from late Day 2 (11 May) or early day 3 (12 May).

Geomagnetic activity is expected to remain Quiet to Unsettled at first on 10 May. Later in the UTC day effects from multiple Earth-directed CMEs are Expected to increase activity to G2-G3/Moderate to Strong levels, with a Chance of G4/Severe Geomagnetic Storm intervals. Similar levels of activity should persist into the start of day 2 (11 May). The X1.1 flare CME of 09 May should then follow around 12/0001UTC, to give a further salient peak of Likely G2, with this potentially being bolstered by the X3.9 - TBC in future guidance. While some reduction in geomagnetic activity is then likely into Day 4, Monday 13 May, confidence at the end of the period is low and the forecast may change should further large Earth-directed CMEs occur.

Energetic Particles / Solar Radiation: High energy protons (greater than 10MeV) now carry an increased Chance of breaching S1 given recent increases observed at GOES18 as well as the prospect of inbound CMEs sweeping up and collecting those in the interplanetary medium. There is now a corresponding Slight Chance of S3 for this reason during the first two UTC days. The chances from here otherwise comprise a comparatively lower but rising risk of further S1-scale events from further proton-rich flare events from AR3664, overlaid on a decreasing contribution from now departed Ex-AR3663.

High energy electron flux is forecast to be at Normal Background to Moderate levels throughout, with associated fluence expected to remain well below the Active (1e8 integrated pfu) threshold.

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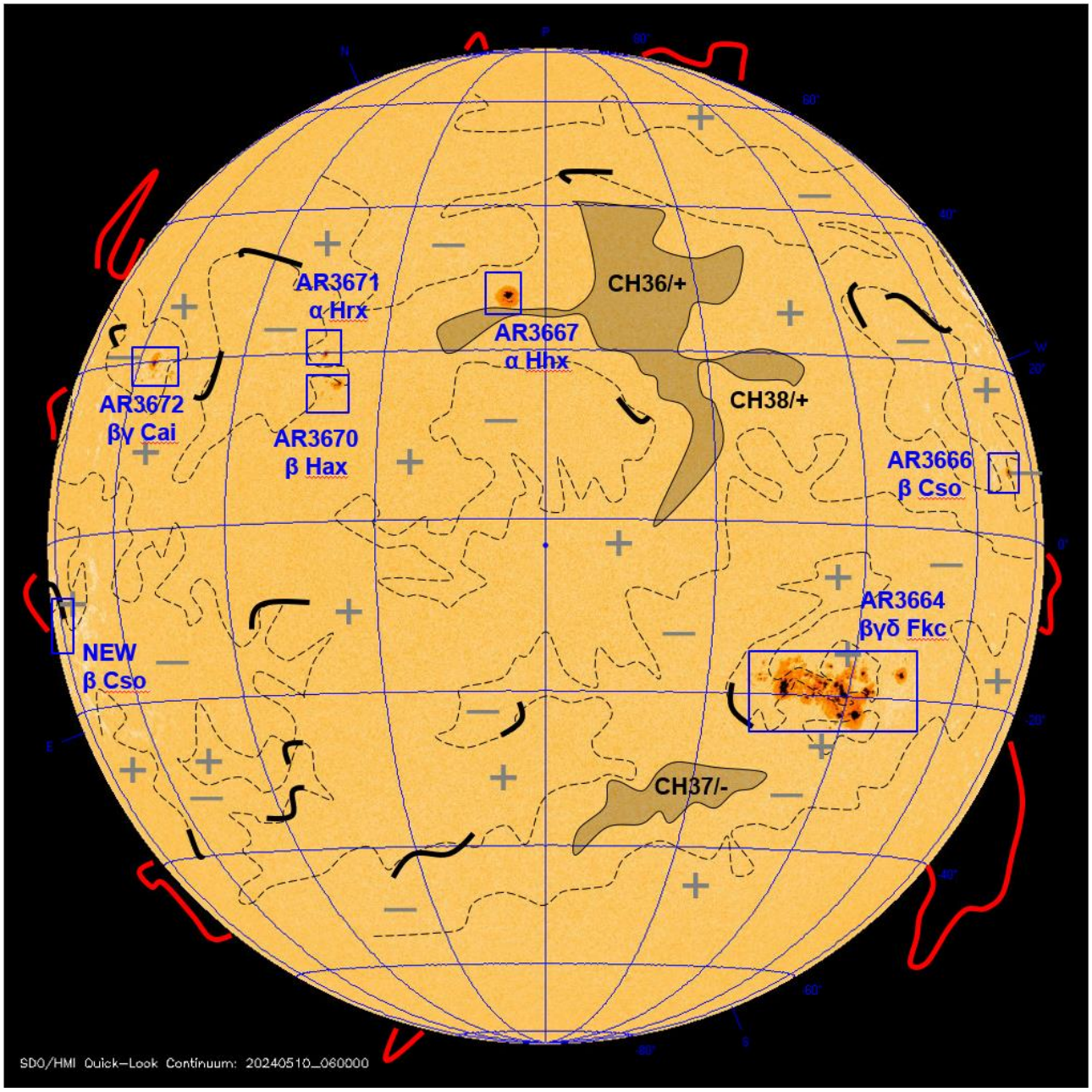
Figure 1. Solar Analysis Valid 10/0600UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

Geomagnetic Storms:

The geomagnetic forecast is CME-dominated, with the main uncertainties being 'when' rather than 'if' CMEs arrive.

Attention is currently on the L1 satellites and to some extent on STEREO A - the latter given it is both more-directly in line for many of the inbound CMEs and is stationed at 0.96AU at present. ACE EPAM LEMS is showing a continued gradual rise in low energy protons - a trend that can be expected to continue until the arrival of the inbound CMEs.

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Multiple Earth-directed CMEs were observed leaving the Sun between 08 and 09 May associated with solar flares from AR3664 in the southwest. Added to this is a large filament liftoff from the northeast disc on 08 May. Due to the relative speed of the various CMEs most are expected to combine into a single larger arrival towards the end of the UTC day on Day 1 (Friday 10 May). The X1.1 mentioned in the 'Solar Activity' section is perhaps the main exception to this, and should arrive later at around 12/0001UTC. The latest and largest flare of the current 24-hour period (X3.9) is undergoing assessment, but could sweep up the X1.1 outlier in a manner similar to events forecast on 10 May - this aspect is to be confirmed.

Other drivers of geomagnetism are expected to be masked and pale in comparison to the CME effects, however should any sizable windows emerge that escape CME influence (considered unlikely), Slightly Elevated solar winds are expected to fall to Background levels on Day 1 (10 May). A minor coronal hole enhancement is possible from late Day 2 (11 May) or early day 3 (12 May), although CH38/+ may well have opened too late for any arising fast wind to intersect the Earth, which would delay the inbound fast wind to the larger and more intense CH36/+.

Geomagnetic activity is expected to remain Quiet to Unsettled at first on 10 May. Later in the UTC day effects from multiple Earth-directed CMEs are Expected to increase activity to G2-G3/Moderate to Strong levels, with a Chance of G4/Severe Geomagnetic Storm intervals. Similar levels of activity should persist into the start of day 2 (11 May). The X1.1 flare CME of 09 May should then follow around 12/0001UTC, to give a further salient peak of Likely G2, with this potentially being bolstered by the X3.9 - TBC in future guidance. While some reduction in geomagnetic activity is then likely into Day 4, Monday 13 May, confidence at the end of the period is low and the forecast may change should further large Earth-directed CMEs occur.

Geo-Magnetic Storm Probability (Exceedance)	**Level**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC) (%)**	**Day 2 (00-24 UTC) (%)**	**Day 3 (00-24 UTC) (%)**	**Day 4 (00-24 UTC) (%)**
Minor or Moderate	**G1 to G2**	No	95	95	80	40
Strong	**G3**	No	60	60	30	10
Severe	**G4**	No	30	30	10	5
Extreme	**G5**	No	10	10	5	1

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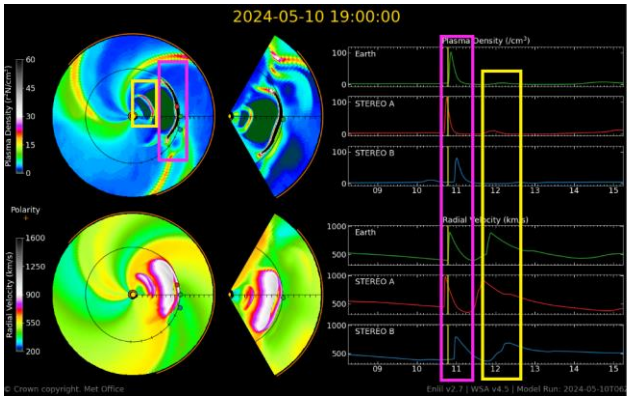
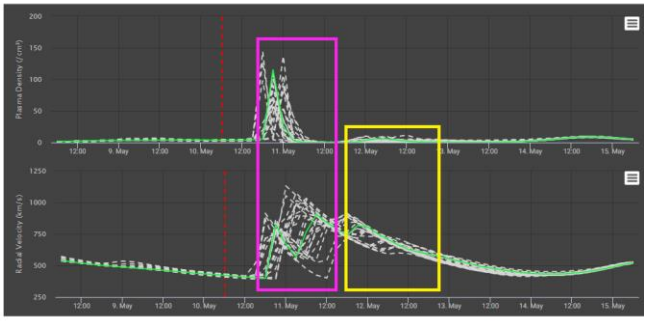
Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
06/0251	Partial	Filament	SE	323 km/s	10/1200 UTC	Slight chance glancing blow
08/0927	Full	AR3664	SW	850 km/s	10/2000 UTC +/- 7 hrs	Merges with last CME
08/1200	Partial	AR3664	SW	715 km/s	10/2000 UTC +/- 7 hrs	Merges with last CME
08/1840	Partial	Filament	NE	600 km/s	10/2000 UTC +/- 7 hrs	Merges with last CME
08/2140	Full	AR3664	SW	902 km/s	10/2000 UTC +/- 7 hrs	Merges with last CME
09/1130UTC	Full	AR3664	SW	1582km/s	10/2000UTC	Final but fastest in cluster, acts to sweep up earlier CMEs
09/2219UTC	Full	AR3664	SW	888km/s	12/0001UTC	Arrival TBC, may be swept up by later CME
Flare occurred 10/0654UTC	Full?	AR3664	SW	Type II 1242km/s	TBC	Pending

Figure 2: Latest MOSWOC Enlil and ensemble (badge time 10/0600UTC). CMEs with 21.5R times from 08/0927UTC to 09/1130UTC inclusive are modelled as arriving in one amalgamated event, nominally around 10/2000UTC +/-7h. Note the very large density associated with this, which dwarfs the separate and salient arrival from the X1.1 around 12/0001UTC, despite their similar inbound speeds. The weight of numbers of individually less remarkable events is the rationale for the elevated risks on this occasion. Note also that the latest X3.9 flare and CME is pending analysis and may yet sweep up its earlier X1.1 compatriot – TBC.





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Radio Blackouts - X-Ray Flares:

Solar activity for much of the past UTC working week has been dominated by the large and complex regions Ex-AR3663 and AR3664. As stated elsewhere, Ex-AR363 now lies on the extreme northwest of the disc and should therefore shortly pass from consideration, however AR3664 will persist throughout the coming four days and dominates the ongoing risks.

There are numerous signs of still another large sunspot region now looming large over the southeastern solar horizon. This is visible on both far-side helioseismographs as well as EUV imagery (e.g. AIA171) and expected returning Carringtons for the period. The extent to which this compensates for the loss of Ex-AR3663 is not known, however AR3664 almost saturates the risk spectrum R1-R3 on its own, and is certainly the dominant consideration for the period.

All considered, there is an initial slight decrease in the risk of R3 given the departure of Ex-AR3663, however the fact X-ray flux has resided within M-class for much of the period means the Expected risk of R1/R2 remains largely unmoved. Any contribution from the eastern solar horizon will be factored in as and when regions present for analysis.

X Ray Flares	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability			(%)	(%)	(%)	(%)
Active	R1-R2 M Class	Yes	95	95	95	95
Very Active	R3 to R5 X Class	Yes	60	50	50	50

Figure 3a: SIDC-ROB derived rogues' gallery of relevant sunspot regions in the UTC working week (five days to 10/1200UTC, with individual pixels being >C-class flares at PROBA-2). Shown are the streak from AR3664 lower centre, Ex-AR3663 upper right, and a new oncoming region far left.

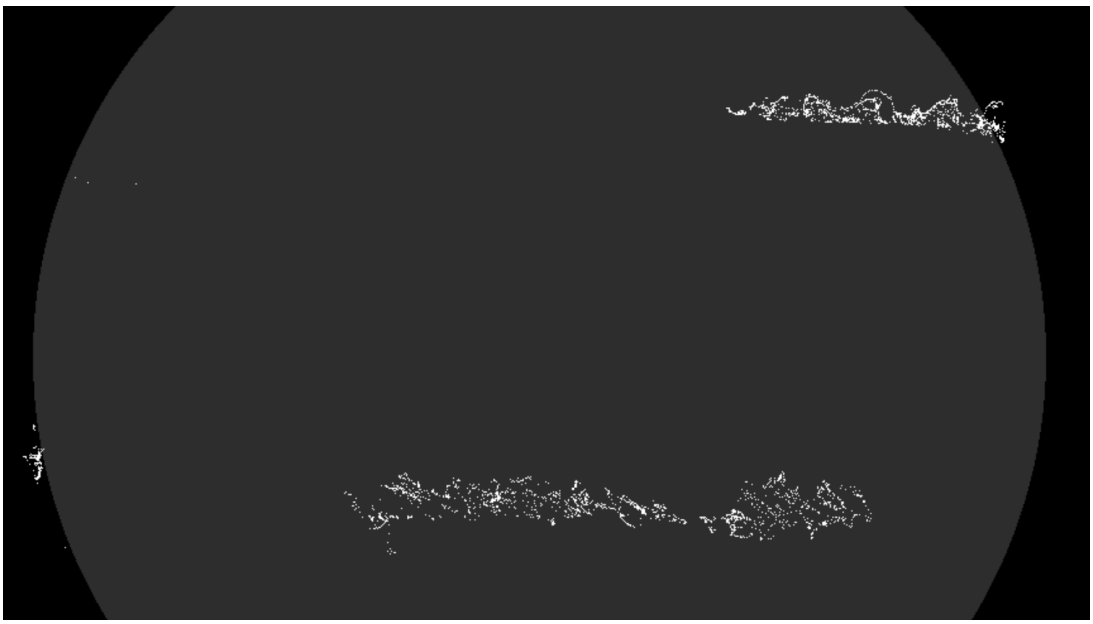

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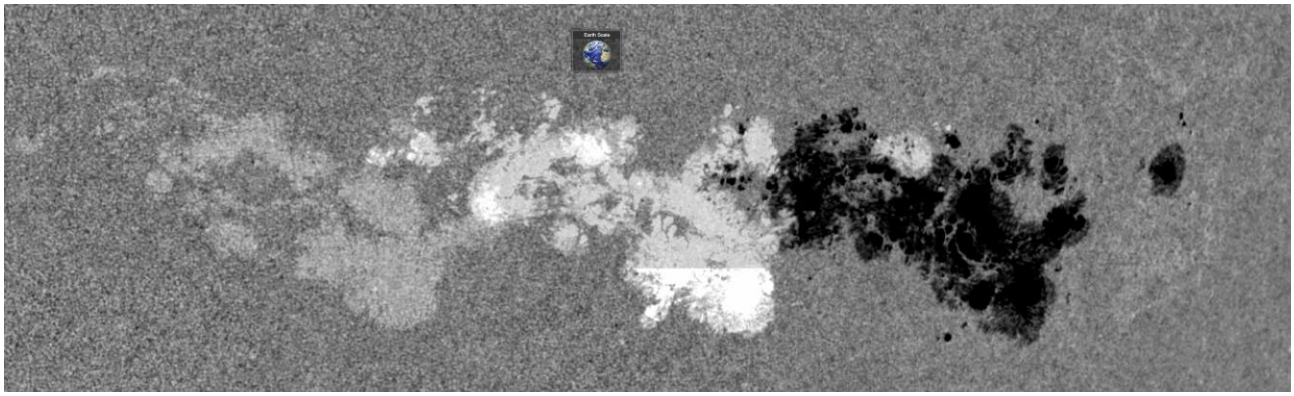
Figure 3b: Helioviewer.org-generated difference imagery for 10/1200UTC HMIIF in black footprint, as well as T-24 and 48 hours in shades of white further east. Also shown is the Earth for scale.



Solar Radiation Storms - (High Energy Protons):

High energy proton flux (greater than 10MeV) observed at GOES18 has begun to exhibit a slowly rising trend, most likely in response to the steady cadence of proton-rich high-M and low-X class X-ray flares, and perhaps their being swept up ahead of inbound CMEs.

The GOES18 >10MeV proton response at present is perhaps surprisingly damped and gradual for the scale of flares and the position of AR3664 on the disc - perhaps more reminiscent of far-sided or far eastern solar hemisphere events at face value - however there is an increasing chance of more direct connection to Earth and more impulsive events in the coming few days as AR3664 nears the western limb. Added to this, the now decreasing risk of S-scale events from Ex-AR3663 must also be considered, albeit with a reducing contribution through the period and with no notable preceding activity.

All considered, the range of S-scale risks has been 'hardened' in the near term (with an upped >=S3 risk) to account for the amalgamated inbound CMEs perhaps sweeping up protons in the interplanetary medium in a separate mechanism from the risk for new proton-rich flares. This upper-tier risk is still only rated as a Slight Chance however, with the >S1 remaining within a Chance. From here, AR3664 is expected to remain on the Earth-facing side for the duration of this period, and so the later forecast evolution is essentially a trade off between the increasing risks from AR3664 and the decreasing contribution from Ex-AR3663.

Radiation Storms	**Level (cm^{-2} sr^{-1} s^{-1})**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability (Exceedance)			**(%)**	**(%)**	**(%)**	**(%)**
Active	**≥ S1**	No	50	50	40	40
Very Active	**≥ S3 ***	No	20	20	5	5
* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)						

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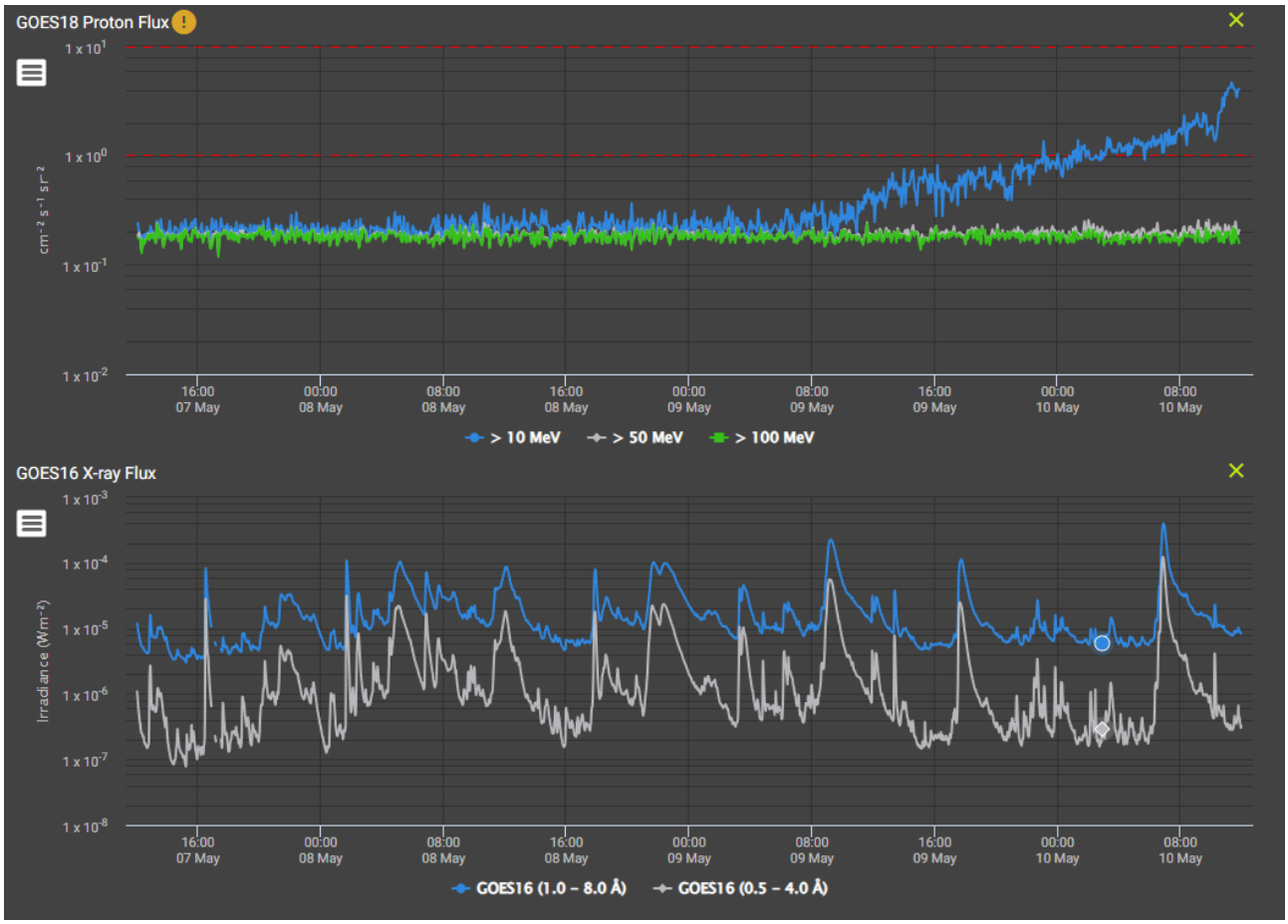
Figure 4: GOES18 high energy proton flux and potential X-ray events asscociated with these (at GOES16). Note the unusually gradual rise for front-sided activity, with this likely to accelerate for any new events as protons perhaps more easily connect with Earth as AR3664 nears the western limb.



High Energy Electrons Event (≥ 2MeV):

High energy electron flux at GOES16 is at Normal Background levels, and is expected to remain at or near this level throughout given the sheer weight of inbound transients and the likely sustained pressure on the Van Allen belts sweeping them inside GEO for some time.

Overall, the 24-hour integrated electron fluence is forecast to remain well below the Active (1e8 integrated pfu) threshold. The Met Office REFM is not considered to offer useful guidance in the coming days by anything other than chance given the transient-dominated forecast.

GEO Electron Environment Probability (Exceedance)	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	1	1
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

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